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INFORMATION PROCESSING FOR TARGET DETECTION AND CLASSIFICATION.(U)
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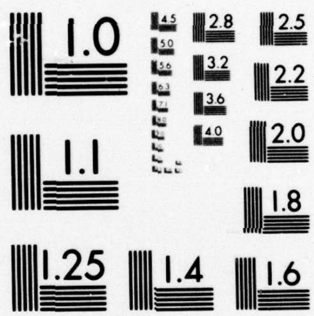

MICROCOPY RESOLUTION TEST CHART
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INTERIM SCIENTIFIC REPORT ON
GRANT NO. AFOSR 74-2611

"Information Processing for Target Detection and Classification"

The goal of the research carried out under the grant is to develop both effective and efficient techniques for the identification of targets by means of radar scattering data. A major effort in the past year was devoted to attain the most efficient utilization of data for the reliable classification of a group of eight aircraft classes. (F-104, F-4, F-14, SR-71, B-1, Mig-19, Mig-21, Mig-23). These classes were chosen to represent the most difficult situation that might be encountered in that both airplanes of similar size as well as widely diverging sizes were to be identified using a very restricted number of identical features. The airplane sizes ranged from 13.49 meters (maximum dimension) for the Mig-19 to 43.58 meters for the B-1, at the same time the very similar sizes of F-104, 16.69 meters (fuselage) and the Mig-21, 16.75 meters (fuselage) were included, in fact the wing spans were also quite similar 6.68 meters for the F-104 and 7.60 meters for the Mig-21. It is apparent that airplanes of very similar dimensions would be difficult to classify, particularly in the above case when viewed from an angle (side view, level flight) that evokes a response from the fuselage alone. In addition, however, the restriction on the number of frequencies permitted, forces a compromise between the lower frequencies which are optimum for the large bodied aircraft and the higher frequencies most appropriate for the smaller airplanes. The tight restriction on the allowed number of frequencies stems from the difficulty in practice of stipulating a multiplicity of radars each operating at a different frequency, or frequency agile radars capable of operating over a very wide range of frequencies. Therefore a study was carried out to compare the more exhaustive uses of the scattering matrix such as the utilization of amplitude and phase and both orthogonal polarization versus the use of additional frequencies.

An extensive study has shown that with the utilization of both polarization and phase, two frequencies were adequate for the reliable classification of the eight classes considered. The optimum two frequencies were found by an exhaustive search of all appropriate frequencies and class combinations. The errors were shown to be negligible for the overwhelming majority of cases with just a handful of cases resulting in measurable errors. The worst case, as expected, was for a sideview of an F-104 vs. Mig-21, which have as mentioned above almost identical lengths, with the maximum error being 18% for an injected noise level as high as 50% of the signal. The study of the optimum single frequency utilizing both polarization and phase information resulted in not much more degraded performance, with the great majority of cases exhibiting very little error and the worst case producing 20% error probability for a noise level of 50% of the signal. The optimum single frequency was found to be in the range most responsive to the small airplanes indicating that the resolution of the larger airplanes is relative error

free for most frequencies used. It should be noted that although a single frequency was used the fact that phase information is utilized may imply an additional reference frequency to obtain that phase. Utilization of amplitude alone at a single frequency has not been found to be adequate for reliable classification except for a rather limited number of classes. The conclusion may thus be drawn that if both polarization and phase information were available reliable classification can be accomplished with two frequencies, with one of these required only for phase reference. Thus if an alternative phase reference can be provided a single frequency is adequate for the classification of targets of a wide variety of types and sizes.

If phase is unobtainable, i.e., a coherent radar is not available, two frequencies would still provide reliable classification but would deteriorate faster with increasing noise and error. Thus, it was found that at noise injection of 30% of signal level the worst error was 18% which occurred for a single observation angle again between a Mig-19 and F-104. It should,though,be stressed that the performance for all other observation angles and all classes considered the errors were substantially lower and quite often negligible. In the exhaustive search for optimum frequencies and frequency combinations it was found that the selection of radar frequencies plays indeed a vital role. Numerous frequency combinations resulted in very large errors, indeed approaching 50%, and in some cases even for small amounts of injected noise, indicating that some of the classes may be overlapping at least in parts of the feature space, i.e., for certain observation angles. The above comments apply to all of the cases discussed above, i.e., when 2 frequencies and both amplitude and phase are used as well as in the single frequency, phase and amplitude case. It is thus apparent that the choice of frequency features determines class separability and cannot be compensated for by other features such as polarization or phase.

One important aspect of the process of classification is the ability to determine that a test case does <u>not</u> belong to any of the training classes and further provide an estimate of its similarity to any of the classes stipulated. This can be accomplished by utilizing hierarchical classification, which has thus received significant attention in the present research effort.

Work on hierarchical classification has included the identification of those frequencies most effective for best cluster separation and selection of constituent classes within these clusters. Generally the best frequencies for this task were found to be the same as those previously reported as optimum for the nearest neighbot technique.

A sequential test was conducted using a clustering approach for classification. Complex scattering data and different polarizations at one and at two frequencies provided six and eight stages for the test respectively. At each stage, the classes were partitioned into two clusters based on noiseless data. As noise was added to the data, thresholds between these clusters for each feature were selected and the corresponding misclassification error evaluated. This approach was surprisingly successful. Data at a single frequency classified

the most proximate four classes with virtually zero error, and any of four frequencies provided this discrimination. When this approach was used with the best two frequencies, six classes were separated with virtually zero error, but no decision was possible for the seven class case. Because of these encouraging results for such a simple approach, the sequential tests were modified to allow three clusters for some features in order to make a decision, at the price of a possible slight increase in misclassification error. These tests showed that eight aircraft could be identified in the presence of noise with virtually zero error when two frequencies were utilized.

An interesting phenomenon was observed during these experiments. Using two frequencies and the same order of tests, an increase in the number of classes to be differentiated led to a decrease in the probability of error. This strange phenomenon is due to the distribution of the classes for each feature, in that only a single threshold is established even though several clusters may be indicated. The introduction of an additional class then drastically changes the location of this single threshold, resulting in lower misclassification error.

Some analytical results have been obtained concerning hierarchical classification. These analyses relate the hierarchical clusters obtained by single and complete linkage techniques to geometrical concepts, and interpret them in that context. One of the most important of these interpretations is that clusters obtained by the complete linkage technique are linearly separable. This interpretation of linear separability of the clusters replaces some of the ad hoc aspects of the clustering algorithm. Another interpretation involves two clusters which are hierarchically grouped together when contrasted to a third cluster still intact. Both minimum and maximum distances between the two grouped clusters are then always less than the minimum and maximum distances respectively between either of the two clusters and the third cluster. These interpretations should allow these clusters to be utilized in other aspects of this research.

So far the sequential clustering algorithm has utilized scalar features as initial determination of performance. The use of multiple-dimensional features should provide excellent discrimination of eight classes in the presence of higher noise levels. Decision zones around the clusters identified in this study can then be determined in order to provide a method for the recognition of an unknown test aircraft. Although the identity of the unknown aircraft cannot be ascertained, at least aircraft on file which have similar characteristics can be indicated.

Another aspect of the aircraft recognition problem has been analyzed and reported in Reference [8]. The analysis is given of a number of characteristics of the optimal Bayes classifier. This applies to the aircraft data when the orientation is not known exactly and in the presence of additive Gaussian noise. This Bayes classifier differs from that described in the literature in that subclasses corresponding to discrete orientations must be considered. One characteristic which was analyzed is the effect of uncertainty in the variance σ^2 of the Gaussian noise upon the decision surface of the Bayes classifier. It

is shown that it is preferable to underestimate σ^2 rather than overestimating this parameter, as a smaller probability of error is obtained.

In work previously reported, comparisons between the Bayes and nearest-neighbor classifiers were described for the subclass situation An analysis of these classifiers for two classes in two and three dimensions has led to necessary and sufficient conditions under which the two classifiers are identical. These conditions are in terms of the geometrical structure of the subclass data points and their relation to the decision surfaces. Also an efficient procedure is given to decide whether two classifiers are equivalent, given the subclass data points.

Another aspect of the Bayes classifier analyzed involves an increase in dimensionality. When multiple orientations are considered and dimensionality is increased, certain counter-intuitive phenomena can occur. It is clear that when dimensionality is increased, the average probability of misclassification will be non-increasing. However, the misclassification probability between classes at a particular orientation can actually <u>increase</u> with the introduction of new features. Sufficient conditions have been obtained for two classes which indicate those configurations of subclasses for which this situation will occur.

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7. S.N. Srihari, and L.J. White, "Pattern Recognition Techniques for Radar Aircraft Identification," Report 3815-2, September 1975, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Grant AFOSR-74-2611 for Air Force Office of Scientific Research.

8. S.N. Srihari, "Comparative Evaluation of Sebestyen and Nearest-Neighbor Classifiers for Invariant Pattern Recognition," Ph.D. Dissertation, The Ohio State University, completion expected December 1975.

9. A.A. Ksienski, "The Inverse Scattering Problem from the Pattern Recognition Point of View." An invited paper to be presented at the National Conference on Electromagnetic Scattering at the University of Illinois on June 15-18, 1976. To be published as a chapter of a forthcoming book on Electromagnetic Scattering.

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A study was made of optimum feature sets for the identification of a set of aircraft that include airplanes of very similar shape as well as strongly dissimilar ones. A trade-off study was also carried out of the relative effectiveness of phase, amplitude, polarization and frequency in the identification process. In particular the optimum frequencies were determined under the utilization constrained of one and two frequencies respectively. The misclassification probabilities were computed and compared for the various choices of features.

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An evaluation of the hierarchical approach for aircraft classification has been made. A sequential test was conducted using aircraft clusters at each stage, and has been shown to be effective. Eight aircraft have been identified using two frequencies with very small misclassification error using data contaminated with moderate amounts of noise. In addition, an analytical study has provided a geometrical interpretation of the hierarchical clustering process.

An analytic study of a number of characteristics of the optimal Bayes classifier for the aircraft data has been made. For the case when the orientation is not exactly known in the presence of additive Gaussian noise, the effect of noise variance upon the decision surface of the classifier was established. Necessary and sufficient conditions have been given for which this optimal Bayes classifier and the nearest-neighbor classifier are identical.